Caspian J. Env. Sci. 2008, Vol. 6 No. 2 pp. 105~112

CJES
Caspian Journal of Environmental Sciences

[Research]

Optimum road spacing of ground based skidding operations in Nowshahr, Iran

M.R. Ghaffarian*[1] and H. Sobhani[2]

1- Institute of Forest Engineering, Department of Forest- and Soil Sciences, University of Natural Resources and Applied Life Sciences, A-1190 Vienna, Austria.
2- Dep. of Forestry, Faculty of Natural Resources, Tehran University, Karaj, Iran, P.O.Box: 31585-4314.
** Corresponding author's E-mail: ghafari901@yahoo.com*

ABSTRACT
The optimum road spacing has been studied by many researches. It is an important step of forest road network planning. The goals of this study are determining the optimum road spacing in Kheiroudkenar forest of Nowshahr in Northern Iran and study of effect of kind of skidder on skidding cost and road spacing. Continues time study method was used to determine the production rate of TAF and Timberjack 450 C skidders in two districts of Kheiroudkenar forest. The production models were developed using stepwise regression method with 46 working cycles for TAF and 44 for Timberjack. The total road construction and skidding cost were calculated for different road spacing for both skidders in one-way and two-way skidding. Based on minimizing the sum of the road and skidding costs, the optimum road spacing was estimated as 1714 m and road density of 5.8 m/ha for two-way skidding by Timberjack and estimated optimum road spacing of TAF was 1600 m and road density of 6.25 m/ha. For one-way skidding, the optimum road spacing of Timberjack was 1143 m and road density of 8.8 m/ha, for skidding by TAF, the optimum spacing was estimated as 1114 m and road density of 8.97 m/ha. The existing road density of Timberjack and TAF skidding sites was 28.16 and 17.11 m/ha respectively which are higher than optimum density. The study of variants method is applied to find the optimal network for existing network in Namkhaneh district.

Keywords: skidder, production, cost, road density, road spacing.

INTRODUCTION
Optimum road density is an important factor to help forest engineers optimize the harvesting costs using a suitable forest road network.

Matthews (1942) developed a model to define optimum road spacing based on minimizing the total cost of skidding and roading from the viewpoint of a landowner. Major variables are removals per ha, skidding cost, road costs and landing costs. Many researchers have used and extended Matthews' model. Additional factors influencing optimum road spacing were identified by several researchers. Thompson (1998) reported as price of products increases, optimum road spacing decreases. Sessions (1986) showed that taxation policies can affect road spacing. Landing costs can also be an important consideration in optimizing road spacing (Peters, 1978). If overhead costs are considered in harvesting costs, it will lead to decreasing road spacing (Thompson, 1992). Yeap and Sessions (1988) showed that equipment opportunity costs can influence road spacing. Consideration of the timing and future volumes entering a permanent road system can also affect the road spacing decision (Wenger, 1984). Recently, Sessions and Boston (2006) formulated a model to minimize the sum of shovel logging costs plus road costs from the landowner's point of view and to maximize profits from the point of view of a logging contractor.

A geometric redefinition of the rectangular road and landing spacing model developed by Matthews (1942), based upon shifting on alternate roads one-half the landing spacing was presented by Bryer (1983). Also the width of road and the size of landing affect the solutions to optimal road and landing spacing (Liu and Corcoran, 1993).

In addition to the landing, the skidding pattern should be considered. Peters (1981) presented charts for solutions for optimum road and simple yarding patterns; yarding directly to a road, yarding directly to a landing, and yarding in an L-pattern to a landing for linear skidding costs. Sessions and Guangda (1987) developed a computer program to derive optimal road and landing spacing for two-way radial, one-way radial and one-way right-angle skidding pattern for both linear and nonlinear skidding costs.

Slope and topography which affect the forest road network were considered as correction factors (terrain factor) by Segebaden (1964). Abeli and Magomu (1993) considered a correction factor equal 4 for two way skidding and 2 for one way skidding. Huggard (1978) used the K factor of road network inefficiency taken on average to be 0.85, and Pentek (2005) used a total correction factor for the theoretical mean skidding distance in order to calculate optimum real mean skidding distance. Heinimann (1997) developed a 3-dimensional road network model considering the non-perpendicular intersection of the first and second order transportation lines as a function of slope and maximum road gradient.

Some researchers studied the optimum road density (RD) and reported different results; such as Picman and Pentek (1998) calculated RD of 14.7 m/ha for ground based skidding system using forest tractors in Croatia. In two and three-stage cable logging systems, three- stage yarding provided cost savings and a substantial increase in road spacing once critical road costs were exceeded (Howard and Tanz, 1989).

The study of short-wood forwarding in Northern Spain indicated the road density for a purpose-built forwarder is 6 m/ha (Spinelli *et al.*, 2003). Ghaffarian *et al.*, (2007) reported the optimal road spacing of 503 m for one way forwarding operations in Southern Austria. In Japan, optimal skid trail spacing was reported about 40 m (Shisshiuchi, 1993).

Soil disturbance is another factor which can be considered in the optimum road spacing of forwarders. Akay and Sessions (2001) developed the model to study the effect of rut depth as limiting factor for optimal road spacing. For their assumed conditions, optimum spacing was 600 m for a large forwarder.

In the Northern forests of Iran, Mostafanejad (1995) indicated that optimal length of skid trail is 250 m and RD equals 28.0 m/ha in the Nekachoub Company. In other management areas of this company, RD was 8.5-9 m/ha for the tree length systems and 10-10.5 m/ha for the cut-to-length system (Naghdi, 2004). Eghtesadi (2000) proposed RD about 19.5 m/ha in the Vaz area. In the Farim Forest Company using a Timberjack 450c cable skidder, the RD was 21.0 m/ha (Lotfalian, 2001). The optimum road spacing for skidding operation has not been studied in Nowshahr. It is necessary to study road spacing in this area while the results can be used in logging planning of this management area.

MATERIALS AND METHODS

Site of study

The first study was carried out in Patom district of Kheiroudkenar forest center in Nowshahr in Northern Iran (Gour Gholami, 2005). In this area, the Taf wheeled cable skidder was used in a selection cutting operation in a mixed stand of Fagus orienttalis and Carpinus betulus in compartment 114 and Quercus sp. and Carpinus betulus in compartment 115. The terrain slope was steep (40%). Minimum and maximum elevation above the sea level was 1100 and 1260 meters, respectively. The annual rainfall is recorded as 1300 mm.

The second study has been done in Namkhaneh district of Kheiroudkenar forest. In this area, the Timberjack 450 C wheeled cable skidder was used in a selection cutting operation in a mixed stand of Fagus orienttalis and Carpinus betulus in the compartment 209 and Quercus sp. and Carpinus betulus in compartment 221. The terrain slope ranged from 30% to 50%. Minimum and maximum elevations above the sea level were 700 and 850 meters, respectively.

In both districts, felling is done motor manually in selection cutting system. After felling, the trees are topped, debranched and bucked to small length log (up to 6 m). Then wheeled skidders are used to extract the logs from forest to the road side. In some cases also mule logging is used. Mule logging is used in these four situations; firstly there is no skid trail available for using skidders or tractors, secondly the cut volume is not so high or timber is scattered in the compartments, thirdly the logging area is too steep and use of tractors is not possible and fourthly after extracting the sawlogs by mechanized systems, firewood or pulpwood are extracted by mules (Ghaffarian, 2003).

Data collection

Jour Gholami (2005) studied cost production of Taf and Timberjack 450 C skidders in this area. He used the continuous time study method in both production studies. The typical work cycle included; travel empty, releasing the winch, choker setting, winching, travel loaded, opening the chokers and stacking. The delays including technical, personal and operational were recorded. The same variables were used in both data collections. Variables included skidding distance, piece volume, load volume, number of pieces per turn and slope of trail. Forty-six working cycles for Taf and forty-four cycles for Timberjack were collected.

The system cost of TAF including fixed, operating and labor cost was 37.94 Euro/h and for Timberjack about 46.91 Euro/h (Jour Gholami, 2005). The developed regression models to predicting the time of skidding were used to study the road spacing.

The road cost in this forestry center included the costs of planning (384.6 Euro/Km), construction of subbase (6837.6 Euro/Km), subgrade construction (11794.8 Euro/Km), culverts and ditches (4273.5 Euro/Km) and road maintenance cost as 15% of roading cost in the 10 years period (349.3 Euro/Km). The roading cost was 23639.8 Euro/Km or 23.64 Euro/m. The interest of investment would be 2.19 Euro considering 18.5% interest rate in Iran. If life period of the forest road is 50 years, the deprecation cost would be 0.47 Euro. The total annual cost of road is sum of interest and deprecation costs as 2.66 Euro/m.

The mean harvesting volume of Namkhaneh district is about 5.41 m^3/ha/year and 1.35 m^3/ha/year for Patom district. The existing road density in Namkhaneh and Patom district was 28.16 m/ha and 17.11 m/ha respectively.

Cost minimization method

In order to determine the optimum road spacing, the skidding cost per m^3 is calculated through the time predicting model by changing skidding distance between minimum and maximum skidding distance observed within the time studies and holding the other variables at the average observed values. The annual roading cost is 2.66 Euro/m. Road density may be evaluated from the following formula (FAO, 1974):

Dist= K/RD

Where

Dist: average extraction distance (km)

RD: road density (m/ha)

K: terrain factor: 4 to 5 in flat terrain

5 to 7 in hilly terrain

7 to 9 mountainous

> 9 very steep Mountain

The local conditions in the study area were mountainous so we assumed a terrain factor (k) of 7. Using the above formula, road density was calculated based on skidding distance.

The total cost per m^3 included road and skidding cost and was graphed to show sensitivity of total road and skidding costs to changes of road spacing. We assumed that the road will be used for two way skidding. Also the optimal road spacing was calculated in one way skidding.

Managing existing forest road network

In this method, the total cost of road construction and skidding costs of seven road networks using existing roads in the Namkhaneh district was calculated. First, the variant was chosen by selecting the desired road branched. In the second step, the average skidding distance was obtained trough the road spacing of each variant. Using the average skidding distance and road density, the skidding and roading costs were determined. The total cost per m^3 was used to find the best variant.

RESULTE

In Namkhaneh district, the production rate of skidding by Timberjack was 8.22 m^3/h (based on free delay hours or net production) and 8.88 m^3/h (including delay times). The skidding costs were 5.69 Euro/m^3 for net production and 5.28 Euro/m^3 considering the gross production. In Patom district where TAF was used to extract the logs, the production rate was 5.93 m^3/h (based on free delay hours or net production) and 8.33 m^3/h (including delay times). The skidding costs per m^3 were 6.39 Euro/m^3 for net production and 4.55 Euro/m^3 based on gross production of TAF.

Model

Using the variables such as skidding distance, piece volume, load volume, number of pieces per turn and slope of trail, the time predicting models were developed by stepwise regression method using SPSS (Jour Gholami, 2005).

Skidding model of Timberjack 450 C

T (min./cycle)= 4.142 + 1.988 × Number of pieces per turn + 0.0176× Skidding distance (m) + 1.093 × Load volume (m^3)

R square: 78.6% and number of observations: 43

The validity of the model was tested using the witness samples. The model was valid at the significance level of 5%.

Skidding model of TAF

T (min./cycle)= 2.323 + 1.819 × Number of pieces per turn + 0.03563× Skidding distance (m) + 0.0764× Slope of trail (%)× Load volume (m^3)+ 0.88× Load volume (m^3)

R square: 86.3% and number of observations: 45

Based on the validity test, the model was valid at the significance level of 5%.

Road spacing

Using Timberjack 450 C in Namkhane district

Table 1. Skidding cost per m^3 as a function of skidding distance holding number of pieces per turn and load at their mean values.

Skidding distance (m)	Skidding time (min.)	Skidding cost (Euro/m^3)
18	10.25	3.98
100	11.69	4.48
200	13.47	5.10
300	15.24	5.71
400	17.01	6.33
458	18.01	6.68

Using a road cost of 2.66 Euro/m and harvesting volume of 5.41 m^3/ha, for two way skidding which is applied in most parts of this compartment, the minimum total cost of 8.306 Euro/m^3 occurred when road spacing is 1714 m (Fig 1). The corresponding road density and average skidding distance are 5.8 m/ha and 600 m respectively.

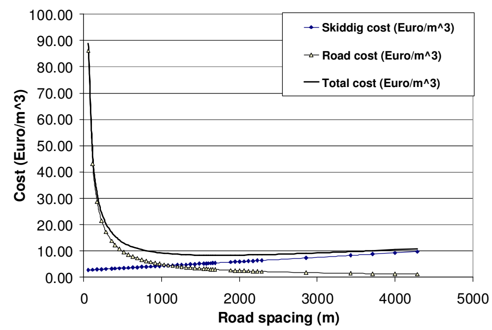

Figure 1. The total cost summary and road spacing for skidder Timberjack on two way skidding

The optimum road spacing depends to road cost, skidding cost, terrain conditions and harvesting volume. Table 2 shows the optimum road spacing for different harvesting volumes, when road cost is held constant at 2.66 Euro/m. To derive such a table, harvesting volume was changed with the constant road cost to compute optimum road spacing.

Table 2. Optimum road spacing using Timberjack for different harvesting volumes

Harvesting volume (m^3/ha)	Optimum road spacing (m)
7.83	1429
6	1657
4	2057
2	2857

The production rate of Namkhaneh district is 7.83 $m^3/ha/year$. Usually the foresters mark the trees less than production rate of the site because of silvicultural regulations in selection cutting.

One way skidding is applied in some parts of this district. In this case, the optimum road spacing would be 1143 m with minimum total costs of 10.68 Euro/m^3. The road density and average skidding distance would be 8.8 m/ha and 800 m.

Using TAF skidder in Patom district

The K factor of 7 was chosen to calculate road density based on skidding distance using formula presented by FAO (1974). Considering road construction cost of 2.66 Euro/m (as Namkhaneh district) and harvesting volume of 1.35 m^3/ha, the total cost per m^3 including road and skidding cost was computed for different road spacing.

Table 3. Skidding cost per m^3 as a function of skidding distance holding number of pieces per turn, slope and load at their mean values.

Skidding distance (m)	Skidding time (min.)	Skidding cost (Euro/m^3)
50	14.17	5.48
100	15.95	5.94
150	17.74	6.40
200	19.51	6.85
250	21.3	7.31
300	23.08	7.77
350	24.86	8.23
400	26.64	8.68
450	28.43	9.14
500	30.21	9.60

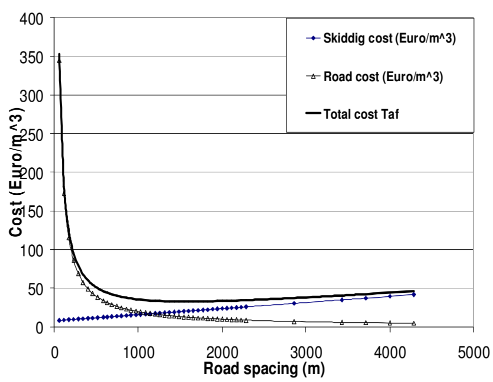

Fig 2. The total cost summary and road spacing for TAF skidder in two way skidding.

In some parts of Patom district two way skidding is applied. In this case, the optimum road spacing and minimum total cost are 1600 m and 32.75 Euro/m^3 respectively. Corresponding road density is 6.25 m/ha and average skidding distance of 560m.

In this logging operation, the effect of different harvesting volume was studied in Table 4.

Table 4. Optimum road spacing using TAF for different harvesting volumes.

Harvesting volume (m^3/ha)	Optimum road spacing (m)
7.83	686
6	743
4	914
2	1314

The one way skidding is mostly applied in Patom district; the optimum road spacing is 1114 m with minimum total costs of 43.07 Euro/m^3. The road density and average skidding distance are 8.97 m/ha and 780 m respectively.

TAF skidder was an old machine which led to increase in delay time (Jour Gholami, 2005). Figure 3 presents skidding time per working cycle for both skidders.

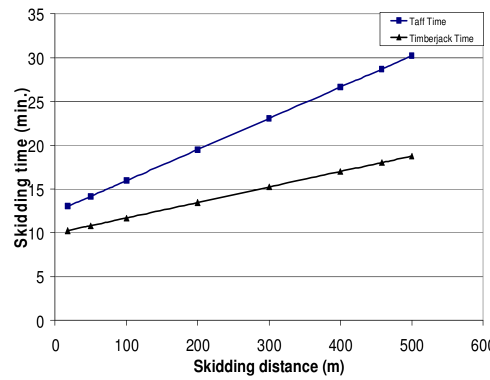

Fig 3. Comparison of time of skidding for TAF and Timberjack skidders

For different skidding distances, skidding time is higher for TAF but an important point is that the time difference in longer distance would be more than short distances.

For different road density, the total cost per m^3 was calculated using TAF and Timberjack skidders (Figure 4).

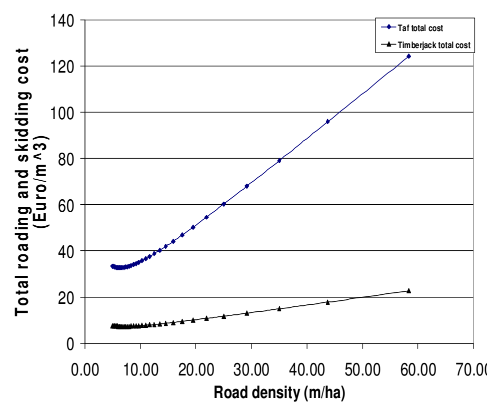

Fig 4. Total cost per m^3 in different road densities for TAF and Timberjack skidders

Figure 4 shows that for different road densities, the total costs per m^3 of TAF skidder is more than Timberjack. The difference of total cost per m^3 is low in the range of 5 to 10 m/ha road density where is near to optimum density and minimum total costs. If road density increases, the cost difference will increase too. For example, in the existing road density of Patom district which is 17 m/ha, the total cost per m^3 for the TAF is 37 Euro more than the total costs for Timberjack.

Managing the existing forest road network in Namkhaneh district

The results of minimization total cost of skidding and road costs in Namkhaneh districts showed that the optimal road density is about 5.8 m/ha. The existing road density is 28.2 m/ha. The logging manager may decide to decrease the road density to reach the optimal.

Among seven variants, the fourth variant with road density of 10.32 m/ha has minimum total cost of 9.07 Euro/m^3. This variant uses two branches including branch 2 and 7 (Figure 5). Therefore, logging manager can eliminate the other road branches in the district to avoid their maintenance cost. Although first branch can be used to access the protected compartments for ecological aims. The branches 4 and 5 can be used to open the next district too.

In Patom district, the terrains are too steep and mountainous. There is only one access road which opens this district. Therefore the existing road density can not be reduced trough closing the road while the exiting road is an opening road for next district which is Namkhaneh. Five compartments with the area of 338.06 ha (37.6% of total district area) in this district are protected because of steepness and low quality of timber. This led to decrease of the harvest area and increase in road density (Figure 6).

Comparison of minimization of total cost by mathematical model method and study of variants in road spacing

The optimum road density based on mathematical model of minimization cost presented the optimum of 5.8 m/ha. The study of possible variants showed that the total costs are minimized at road density of 10.95 m/ha. It seems that mathematical model does not consider the possibility of road construction based on soil and topography condition. Although one of the most important limiting factors of forest road design is slope of the ground in mountainous and rough terrains. Furthermore the shape of district to be opened by road network can affect the road density. These mentioned reasons can clarify the higher optimum road density in study of possible road network compared to mathematical graphing method.

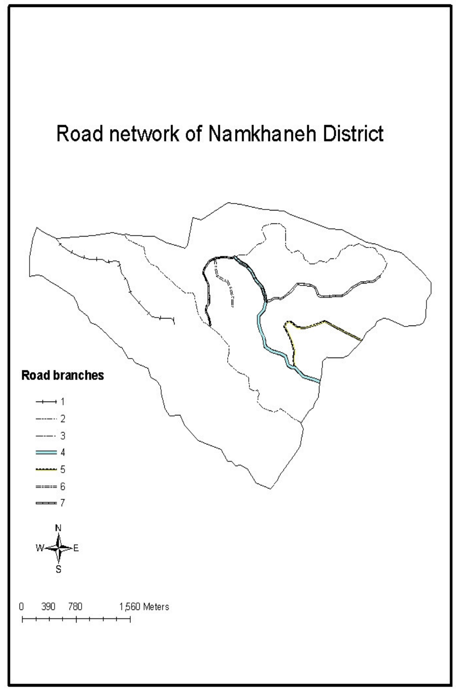

Fig 5. Existing road network of Namkhaneh.

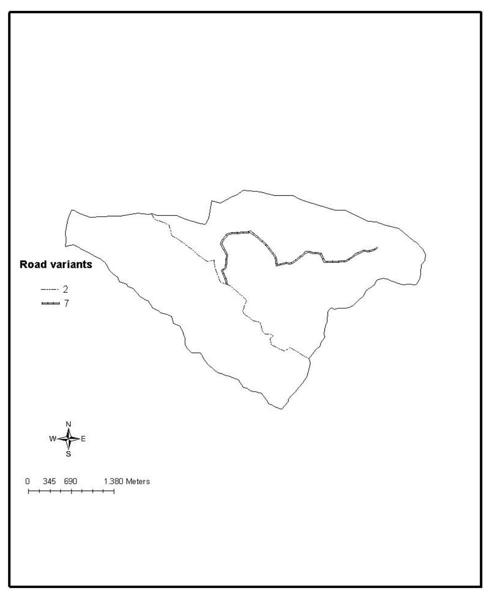

Fig 6. Optimum road network of Namkhaneh using study of possible road variants.

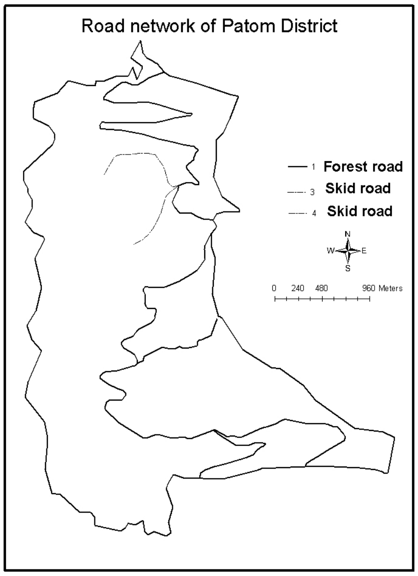

Fig 7. Exsiting road network of Patom district.

DISCUSSION

The optimum road spacing was studied based on minimization of total skidding and road construction costs which is useful for logging planning in this area.

The existing road density in both districts is so high which increase highly the total cost per m^3 (in Namkhaneh and Patom the total cost are 8.7 and 13.3 Euro/m^3 higher than minimum cost respectively), so it is necessary to apply optimum road density for opening up the other districts of Kheiroudkenar forest to minimize the total forest harvesting cost. It can be proposed to eliminate some of the existing roads to avoid their maintenance cost. The abundant roads can be used for access to protect and genetic reserved stands in protected areas of district. Also some of them can be used to open the next districts.

In Patom district, based on figure 4, it is recommended to use Timberjack 450 C instead of TAF because of less skidding cost which also would lead to decrease road density and reduce total cost per m^3. Using the correct skidding machines which have less skidding cost, not only reduce the skidding costs but also will help minimize the total cost of logging block.

Depending on the silvicultural treatments and environmental issues and based on tables 2 and 4, if the harvesting volume decreases, the optimum road spacing should be increased and vice versa.

The mixed integer programming can also be applied to optimize the road spacing for the next study.

The multiobjective optimization can be used to consider different ecological and economical factors or heuristic and spatial procedure to find the possible optimum road network in future.

REFERENCES

Abeli, W.S. and Magomu, G.M. (1993) Optimal road spacing for manual skidding sulkies, *Journal of Tropical Forest Science*. **6**(1), 8-15.

Akay, A. and Sessions, J. (2001) Minimizing road construction plus forwarding costs under a maximum soil disturbance constraint. *The International Mountain Logging and 11th Pacific Northwest Skyline Symposium December 10-12*, Seattle, Washington, USA: pp. 268-279.

Bryer, J.B. (1983) The effects of a Geometric Redefinition of the Classical Road and Landing Spacing Model Through Shifting, *Journal of Forest Science*. **29**(3), 670-674.

Eghtesadi, A. (2000) Study of transportation network and machinery in Vaz Forest Area, *PhD Thesis, Azad University*.

FAO, (1974) *Logging and log transport in tropical high forest.* Rome. pp. 50-52.

Ghaffarian, M.R. (2003) Study of production-cost and damages to residual stands (seedling &soil) in Mule Logging. *MSc thesis, Faculty of Natural Resources, University of Tehran.*

Ghaffarian, M.R., Stampfer, K. and Sessions, J. (2007) *Optimum road spacing of forwarding operations: a case study in Southern Austria.* 40th International Symposium on Forestry Mechanization. October 7-11. Vienna, Austria.

Heinimann, H.R. (1997) A computer model to differentiate skidder and cable-yarder based road network concepts on steep slopes, *Journal of Forest Research (Japan).* **3**(1), 1-9.

Howard, A.F. and Tanz, J.S. (1990) Optimal spacing for multistage cable yarding operation, *Canadian Journal of Forest Research.* **20,** 669-673

Huggard, E.R. (1978) Optimum road spacing, *Quarterly journal of forestry*. **72**(4), 207-210.

Jour Gholami, M. (2005) Study of efficiency, production and cost of large and small skidders (Case study of TAF and

Timberjack 450 C). *MSc Thesis, Faculty of Natural Resources, Tehran University*

Liu, S., and Corcoran, T.J. (1993) Road and landing spacing under the consideration of surface dimension of road and landings, *Journal of Forest Engineering.* **5**(1), 49-53.

Lotfalian, M. (2001) Study of factors influencing optimum road density in Sangdeh-Mazandaran, *PhD Thesis, Faculty of Natural Resources, Tehran University.*

Matthews, D .M. (1942) *Cost control in the logging industry. McGraw-Hill,* New York. pp. 374.

Mostafanejad, A. (1995) Study of cost production of Timberjack 450 C and optimal length of skid trails, *MSc Thesis, Faculty of Natural Resources, Tehran University*

Naghdi, R. (2004) Study of optimum road density in tree length and cut to length systems, Ph.D thesis, Faculty of Natural Resources, University of Tarbiat Modarres. pp. 177.

Pentek, T., Picman, D., Potocnik, I., Dvorscak, P. and Nevecerel, H. (2005) Analysis of an existing forest road network. Croatian *Journal of Forest Engineering.* **26** (1), 39-50.

Peters, P.A. (1978) Spacing of roads and landings to minimize timber harvest cost, *Journal of Forest Science.* **24**(2), 209-217.

Peters, P.A. (1981) *Road and landing spacing model.* Forest operations analysis, IUFRO World Congress, Kyoto, Japan, September 6-12, 1981, 51-68.

Picman, D. and Pentek, T. (1998) *The influence of forest roads building and maintenance costs on their optimum density in low lying forests of Croatia.* Proceedings of the Seminar on Environmentally Sound Forest Roads and Wood Transport in Sinaia, Romania, Food and Agriculture Organization of the United Nations, Rome. pp. 87-102.

Segebaden, G.V. (1964) Studies of cross-country transportation distances and road net extension, Studia Forestalia Suecica, Nr.18.

Sessions, J. (1986) Can income tax rules affect management strategies for forest roads, *Western Journal of Applied Forestry*. **1**(1), 26-28.

Sessions, J. and Guangda, L. (1987) Deriving optimal road and landing spacing with microcomputer programs, *Western Journal of Applied Forestry.* **2**(3), 22-26.

Sessions, J. and Boston, K. (2006) Optimization of road spacing for log length shovel logging on gentle terrain, *Journal of Forest Engineering.* **17**(1), 67-75.

Shishiuchi, M. (1993) Optimal Skid Trail Spacing for Small Vehicles in Thinning, *Journal of Forest Engineering.* **5**(1), 29-32.

Spinelli, R., Owende. P., Ward, S. and Torneo, M. (2003) Comparison of shortwood forwarding systems used in Iberia. *Silvia Fennica.* **38** (1), 85-94.

Thompson, M.A. (1988) Optimizing spur road spacing on the basis of profit potential. *Forest Product Journal.* **38**(5), 53-57.

Thompson, M.A. (1992) Considering overhead costs in road and landing spacing models, *Journal of Forest Engineering*. **3**(2), 13-19.

Wenger, K. (1984) *Cost control formulas for logging operations. p. 560-563 in Forestry Handbook*, 2nd Edition. Society of American Foresters. John Wiley and Sons. New York. pp. 1335.

Yeap, Y.H. and Sessions, J. (1988) Optimizing spacing and standards of logging roads on uniform terrain, *Journal of Tropical Forest Science.* **1**(3), 215-228.

(Received: Oct. 4- 2007, Accepted Apr. 30-2008)